INVESTMECH (Pty) Ltd

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Assignment Guideline

The following points are important to remember:

1. You must complete the assignment in this MS Word document, and rename the file as: Assignment by Student Name (Student Number).doc. Excel files shall be saved as Assignment by Student Name (Student Number).xls
2. Submit the assignment and Excel file (if applicable) by e-mail to: **mheyns@investmech.com.**. No faxed assignments will be evaluated. Please submit the documents in MS Word format to allow me to make changes, comments and mark it directly in the document. This will also allow detail feedback on your assignment.
3. Copy and paste all diagrams, tables, figures, etc. Into this document.
4. Include proper referencing to detail according to the Harvard Method.
5. Hand sketches may be scanned and copied into the document.
6. Delivery date: see www.investmech.com/fatigue .
7. Please contact me at the following should you require assistance:
    a. 082 445-0510
    b. 012 664-7604
    c. mheyns@investmech.com
8. The following documents make part of this assignment:
    a. This document.
    b. Class notes and applicable standards.
    c. Presentations used in class.
9. Clearly articulate and motivate assumptions made, steps followed and application of theory/equations.

1. GENERAL USE OF THE IDEAS [WEIGHT = 10/10]

1.1. Problem Statement

Figure 1 shows a photograph of the Gautrain Centurion Station. As shown, on the platform several concrete columns support 4 branch pipe sections that support the roof super structure. Figure 2 shows a closer view of one vertical support and Figure 3 shows the detail of the 4 branched pipe sections.

Figure 1: Roof support super structure at the Gautrain Centurion station

Figure 2: Support columns on the platform

Questions are based on this joint

Figure 3: Connection of the steelwork on the concrete column

Questions:

1. Why was round tube sections (pipe sections) used for the construction of these parts of the roof support super structure? **[10%] 3**
2. The yellow encircled section in Figure 3 shows the detail of the connection between the tubes and the concrete columns. Comment on this configuration and discuss stress distribution at this joint. **[20%] 3**
3. Where is the most likely position(s) where cracks will first initiate if assumed that the pipe section loaded end at the roof is subject to vertical forces only. **[10%] 2**
4. What detail category would you recommend for the nominal stress based fatigue design of the yellow encircled joint? Clearly motivate your answer. **[20%] 2**
5. What effects could generate varying loads on the joint? **[20%] 3**
6. Make a sketch of another joint design between the pipe and the platework shown in Figure 3. Clearly motivate why your modification will give a different fatigue life (could be higher or lower). Note, for this question you must produce a different way of connecting the pipe with the pates and explain why it has a higher of lower fatigue strength than the joint shown in Figure 3. **[20%] 3**

[Scale to the question relative weight]

1.2. Answer

Question 1

In this case round sections:

1. Do not collect debris and incrustation.
2. Can be easily cleaned.
3. Offers an ergonomic & esthetical design.
4. Offers same strength around any transverse axis.
5. The material is distributed optimally for torsional loading.

Student may list different reasons. Evaluate according to application. Only one good reason required.

Mark out of 3. More than 3 correct answers still have 3.

Question 2

Student must indicate assumptions for the joint, typically as follows:

It was assumed that the joint consist of the end-sealed pipe fillet welded to the platework.

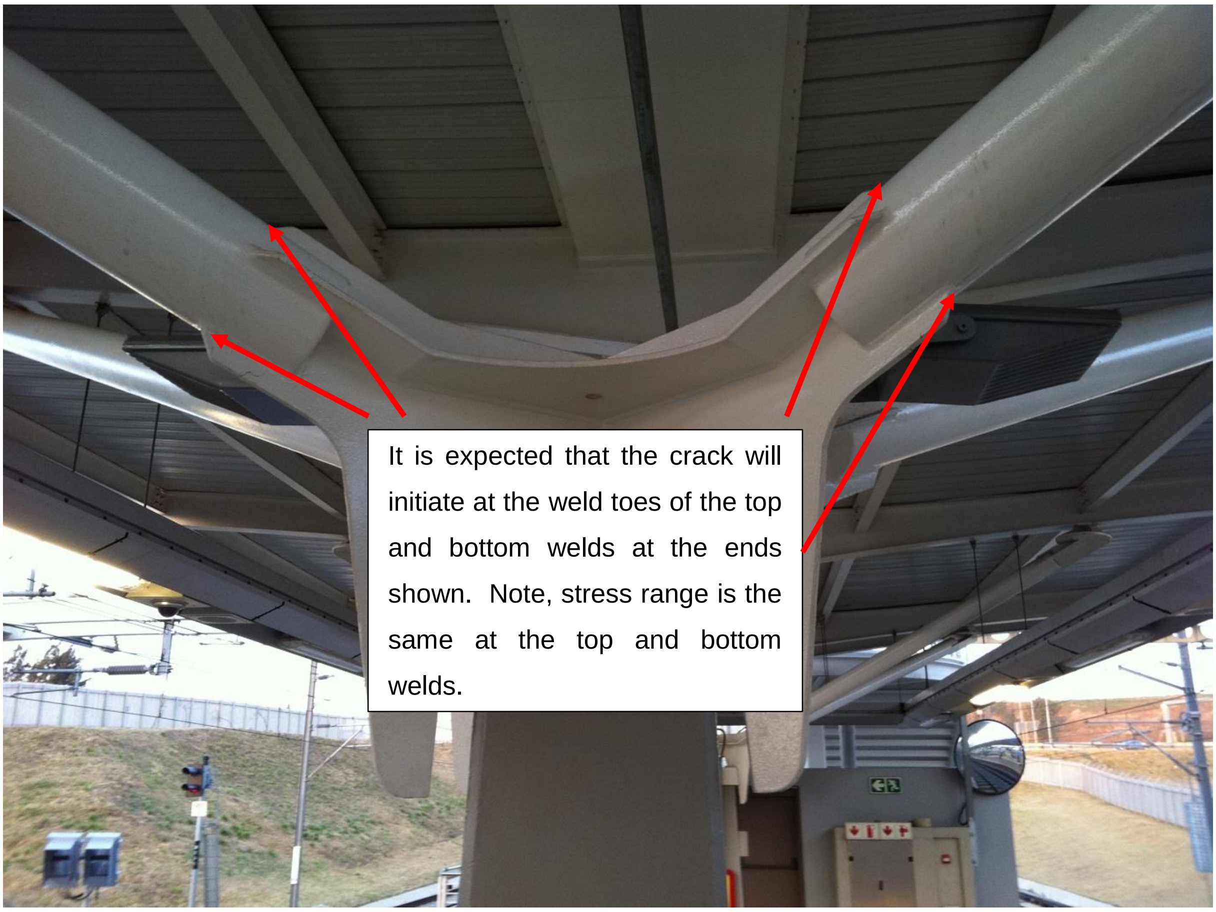
A stress concentration will exist at the end of the plate welded to the pipe due to the bending moment and axial stresses. The predominant bending moment will be as a result of the vertical forces on the end of the built-in beam joined to the roof.

Note, there are many options here. For example, the student could have assumed that the pipe has been slotted and that the plates fit inside, etc. Mark according to student description of stress distribution based on assumptions presented.

Mark out of 3.

Question 3

At the weld toes shown below.



It is expected that the crack will initiate at the weld toes of the top and bottom welds at the ends shown. Note, stress range is the same at the top and bottom welds.

Question 4

Because the section along the length of the pipe will transfer loads gradually to the bottom end where the remainder of the plates are, for calculation of stress at the end of the gusset, the gusset may be modelled as a long attachment. The student can select any of the following with proper motivation:

1. EN 1993-1-9, Table 8.4, Detail 1 with Detail Category 56 for crack initiation at weld toe.
2. EN 1993-1-9, Table 8.4, Detail 2 with Detail Category 71 for crack initiation at weld toe.
3. EN 1993-1-9, Table 8.6, Detail 2 with Detail Category 63 for crack initiation on the plates.

Mark out of 2

Question 5

Variable amplitude loading on an inaccessible roof as in this case could be caused by:

1. Wind loads.
2. Vortex shedding by wind loads.
3. Pressure pulses by passing trains.
4. Low cycles due to snow/hail build-up.
5. Temperature effects because in this case it is clear that the roof trusses will potentially operate at higher temperature than the supporting pipe beams.

Evaluate the thinking of the student. Exact reconstruction of this list not required.

Mark out of 3.

Question 6

There are many answers possible here. Evaluate conceptually by considering the following aspects.

Mark out of 3

Evaluate the following:

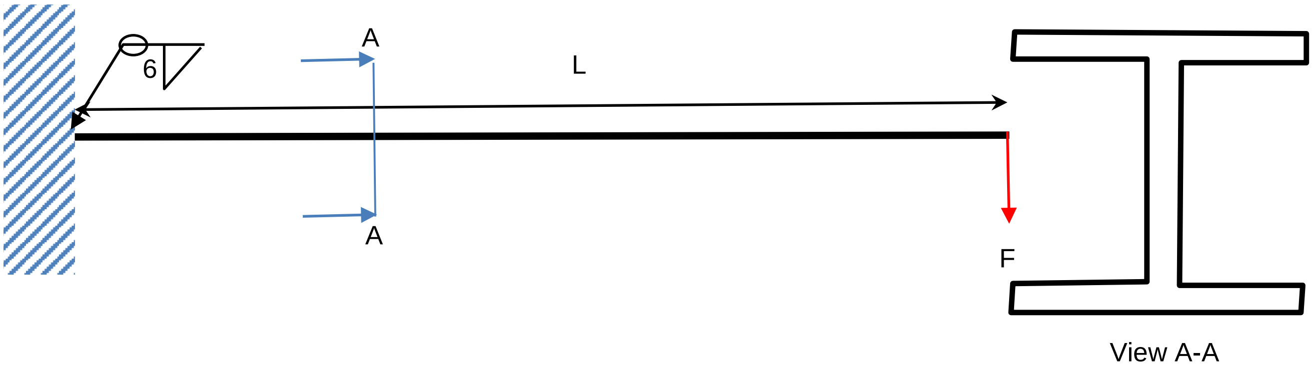
1. Can the student produce an end connection that will work and provide the static resistance required? Note, no calculations are required, evaluate conceptually.

2. Can the student identify the weak point from fatigue point of view of his design based on the information in EN 1993-1-9 Table 8.1 and further?
3. Does the student understand the fact that stress concentrations will be generated at the end-connection and does the student articulate this fact? Note, stress concentrations due to the geometry of the weld will always be present at end connections. Even if saddles are used, there will still be a weak point at the weld toe. Students may choose saddles due the additional cross-section where the welds are. But, they should then demonstrate the low detail category at the weld toe.

2. BEAM DESIGN [WEIGHT = 10/10]

2.1. Problem statement

The sketch below shows the dimensions of a cantilever beam design where an all-around 6 mm fillet weld is used at the end connection. The service life of the cantilever beam is 3 million cycles of cyclic loading. The period in years for of beam use is not known. The length is $L = 3\,000$ mm.



The beam is manufactured of a parallel flange I-beam with designation 203x113x30. The material of the beam is 300W structural steel. Cross-section parameters for the beam can be obtained from: http://www.tubecon.co.za/en/technical-info/tubecon-wiki/i-sections-parallel-flange-universal-beams .

Questions:

1. What force range(s) would you allow on the beam for a design philosophy of safe life with high consequence of failure for 5% probability of crack initiation at the following points (clearly motivate your assumptions and explain the steps followed to obtain the answer): 13
    a. At the fillet weld toe. **[20%]**
    b. In the parent metal not close to a weld toe or other stress concentration. **[10%]**
    c. At the fillet weld root. **[10%]**
2. What is your opinion on the use of a 6 mm fillet weld for fatigue design of the connection? **[10%] 1**
3. What could be done to improve the fatigue strength of the weld detail? **[20%] 1**
4. What force range can be applied if the weld toe was improved by burring? **[10%] 2**
5. To what extent and under what conditions would surface protection improve the life of the joint? **[10%] 1**
6. How would you change the design to have a more durable product? This could be the cross-section, layout with the cantilever, etc. **[10%] 1**

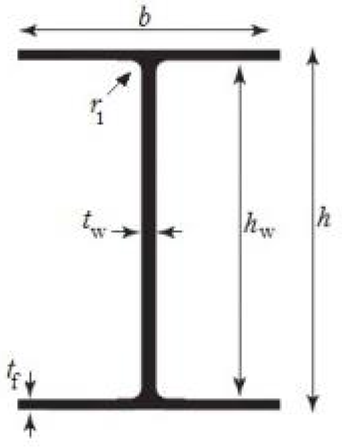
2.2. Answer

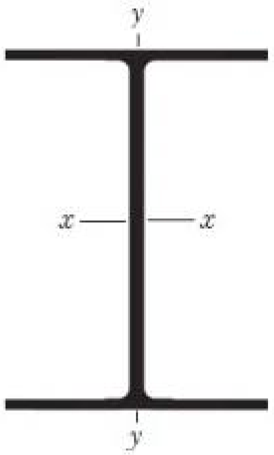
Question 1 **[13 Marks as allocated]**

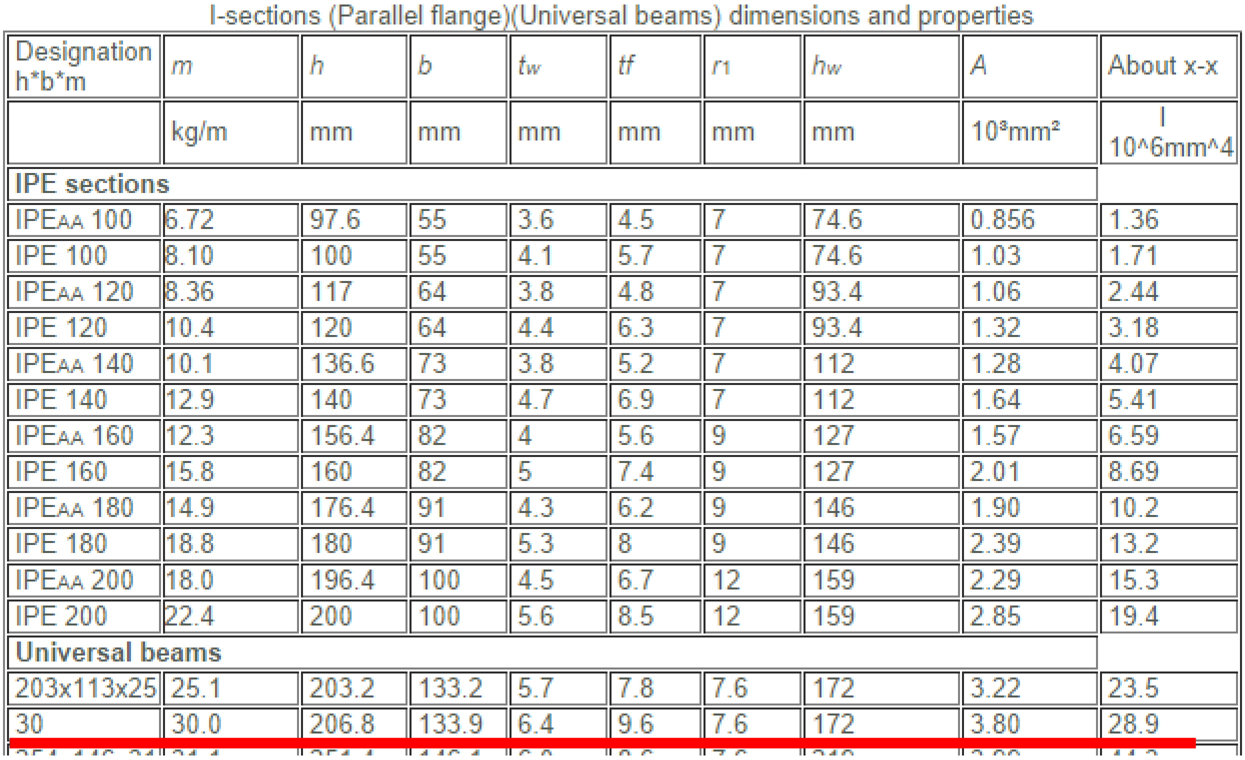
Section dimensions

The beam cross-section properties are as shown below.

1 Mark for using correct detail





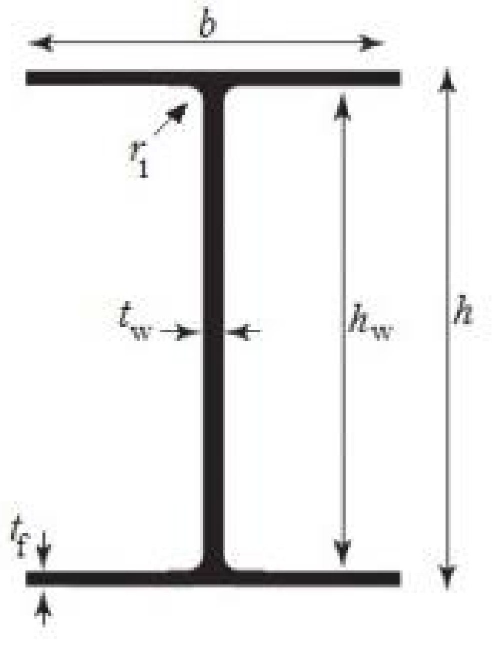


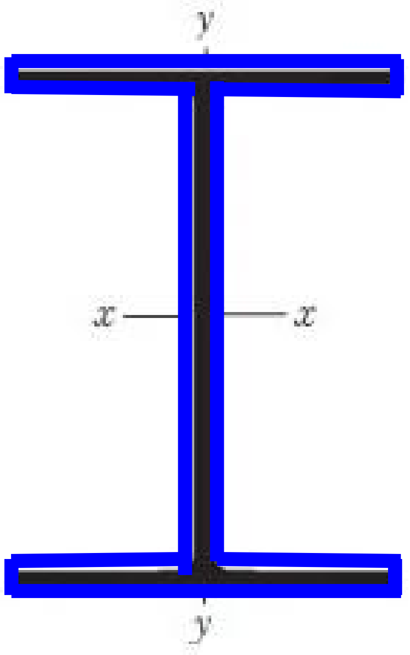
I-sections (Parallel flange)(Universal beams) dimensions and properties

Designation h*b*m	m	h	b	tw	tf	r1	hw	A	About x-x
	kg/m	mm	mm	mm	mm	mm	mm	10^3mm^2	I 10^6mm^4
IPE sections									
IPEAA 100	6.72	97.6	55	3.6	4.5	7	74.6	0.856	1.36
IPE 100	8.10	100	55	4.1	5.7	7	74.6	1.03	1.71
IPEAA 120	8.36	117	64	3.8	4.8	7	93.4	1.06	2.44
IPE 120	10.4	120	64	4.4	6.3	7	93.4	1.32	3.18
IPEAA 140	10.1	136.6	73	3.8	5.2	7	112	1.28	4.07
IPE 140	12.9	140	73	4.7	6.9	7	112	1.64	5.41
IPEAA 160	12.3	156.4	82	4	5.6	9	127	1.57	6.59
IPE 160	15.8	160	82	5	7.4	9	127	2.01	8.69
IPEAA 180	14.9	176.4	91	4.3	6.2	9	146	1.90	10.2
IPE 180	18.8	180	91	5.3	8	9	146	2.39	13.2
IPEAA 200	18.0	196.4	100	4.5	6.7	12	159	2.29	15.3
IPE 200	22.4	200	100	5.6	8.5	12	159	2.85	19.4
Universal beams									
203x113x25	25.1	203.2	133.2	5.7	7.8	7.6	172	3.22	23.5
30	30.0	206.8	133.9	6.4	9.6	7.6	172	3.80	28.9

Sketch of the weld group

The weld group is indicated in blue on the right sketch of the figure below. The throat size of the weld is $\frac{6}{\sqrt{2}} = 4.2\ mm$. Note, in the case it will be assumed that the section of the fillet weld under compression does not include base contact bearing in the joint. This is a valid assumption for fillet welds. However, if partial penetration groove welds were used, contact bearing by the base metal for parts under compression must be added to the area of the weld. This is not the case in this problem. We only need to evaluate the fillet weld throat area.



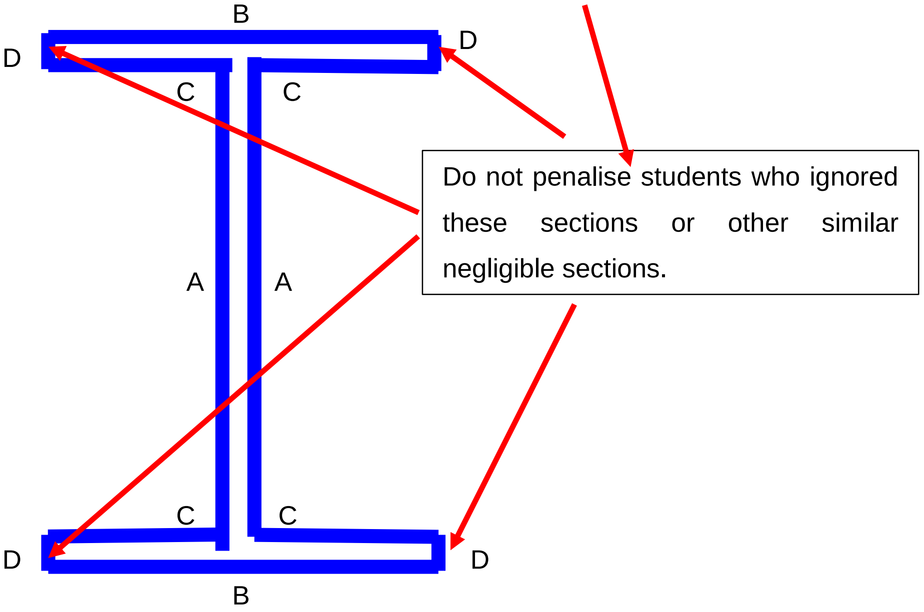


The weld group without the I-beam is shown below. The projected plane for the weld group is 4.2 mm. For calculation purposes, a value t will be used to indicate the weld throat thickness. Further, the second moment of area for horizontal welds around the neutral axis along the weld will be ignored.

The second moment of area of the weld group for bending around the x-axis is:

$$I_{xx} = \overset{A}{2\times\frac{1}{12}th_w^3} + \overset{B}{2\times bt\left(\frac{h}{2}\right)^2} + \overset{C}{2\times(b-t_w)t\left(\frac{h_w}{2}\right)^2} + \overset{D}{4\times\left[\frac{1}{12}tt_f^3+tt_f\left(\frac{h_w}{2}+\frac{t_f}{2}\right)^2\right]}$$

3 Marks for Ixx



Do not penalise students who ignored these sections or other similar negligible sections.

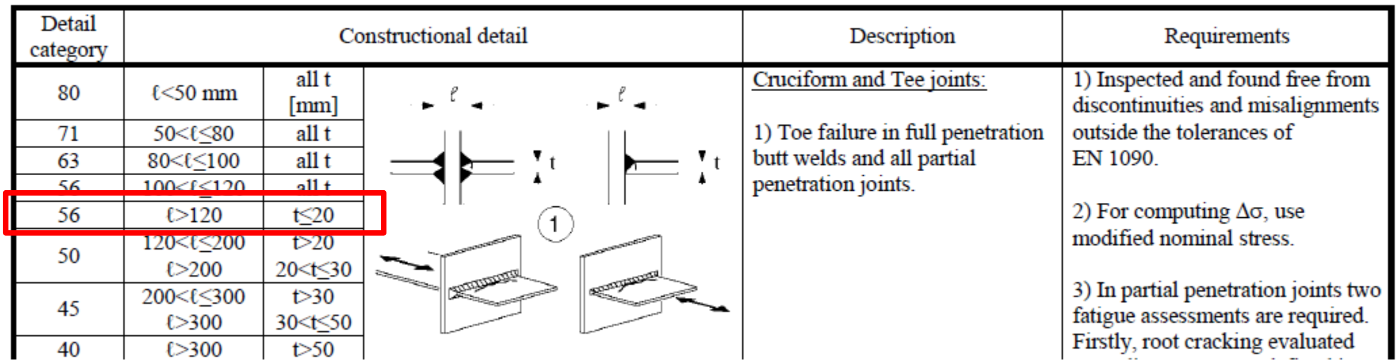
Detail categories

For the base metal the detail category is 160 according to EN 1993-1-9 Table 8.1 Detail 2.

1 Mark

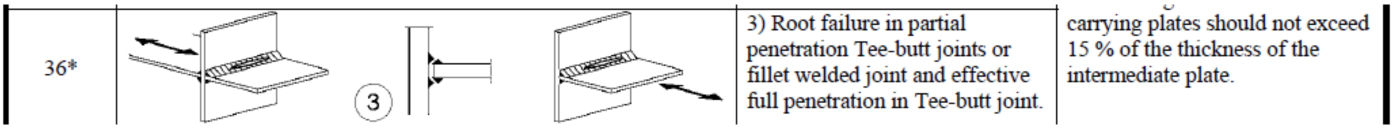
For crack initiation at the weld toe, the detail category is 56 according to EN 1993-1-9 Table 8.5 detail one for $l > 120$ and $t \leq 20$ (see figure below).

1 Mark



Detail category	Constructional detail			Description	Requirements
80	ℓ<50 mm	all t [mm]		Cruciform and Tee joints: 1) Toe failure in full penetration butt welds and all partial penetration joints.	1) Inspected and found free from discontinuities and misalignments outside the tolerances of EN 1090. 2) For computing Δσ, use modified nominal stress. 3) In partial penetration joints two fatigue assessments are required. Firstly, root cracking evaluated
71	50<ℓ≤80	all t			
63	80<ℓ≤100	all t			
56	100<ℓ≤120	all t			
56	ℓ>120	t≤20			
50	120<ℓ≤200 ℓ>200	t>20 20<t≤30			
45	200<ℓ≤300 ℓ>300	t>30 30<t≤50			
40	ℓ>300	t>50			

For crack initiation at the weld root the detail category is 36 according to EN 1993-1-9 Table 8.5 Detail 3 as shown below.



36*		3) Root failure in partial penetration Tee-butt joints or fillet welded joint and effective full penetration in Tee-butt joint.	carrying plates should not exceed 15 % of the thickness of the intermediate plate.

Partial factor for fatigue

According to the detail supplied, the assessment method is damage tolerant with a high consequence of failure that gives a partial factor for fatigue strength of 1.35 as shown below.

1 Mark

Table 1: Partial factor for fatigue strength γ_{Mf}

Assessment method	Consequence of failure	
	Low Consequence	High Consequence
Damage tolerant	1.00	1.15
Safe Life	1.15	1.35

Allowable stress

The allowable stress for the different detail category is then calculated from the S-N curve as follows:

$$\Delta\sigma_R = \frac{\Delta\sigma_C}{\gamma_{Mf}}\left(\frac{N_C}{N_R}\right)^{\frac{1}{m}}, where\ m = 3$$

Based on this, the allowable stresses are:

Condition	Allowable Stress Range [MPa]
Base metal	103.5
Crack initiation in weld toe	36.2
Crack initiation at weld root	23.3

3 Marks

Allowable force range

The relationship between bending moment and the stress range is:

$$\begin{aligned}\sigma &= \frac{My}{I_{xx}} \\ &= \frac{M}{Z} \\ M &= \sigma Z\end{aligned}$$

The bending moment in this case is:

$$\begin{aligned}M &= FL \\ F &= \frac{M}{L}\end{aligned}$$

Where $l = 3\ m$.

Results

The equations were programmed in the code shown below from which the allowable force ranges for a 75% confidence level of 5% probability of crack initiation after 3 million cycles are:

1. For the base metal $\Delta F = 9.6\ kN$
2. For crack initiation at the weld toe: $\Delta F = 3.4\ kN$
3. For crack initiation at the weld root: $\Delta F = 2.1\ kN$

3 Marks for correct calculation of force

Matlab Filenam: WeldAss2014P3

```
% Note on the index i
% i=1 is for the base metal
% i=2 is for weld toe crack initiation
% i=3 is for crack initiation in the weld root

%  Problem WeldAssP3
L=3;
% Beam dimensions
I_xx=28.9E6*1e-12  % [m^4]
h=0.2068;
b=0.1339;
t_w=0.0064;
t_f=0.0096;
h_w=0.172;  %[m]

%  Weld dimensions
t=0.006/sqrt(2);
I_xxw=2*1/12*t*h_w^3 ...
   + 2*b*t*(h/2)^2 ...
   + 2*t*(b-t_w)*(h_w/2)^2 ...
   + 4*(1/12*t*t_f^3 + t*t_f*(h_w/2+t_f/2)^2)
Z=[I_xx/(h/2) I_xx/(h/2) I_xxw/(h/2)]

% FATIGUE CALCULATIONS
gamma_Mf=1.35
N_C=2e6;
N_R=3e6;
K_burr=1.3;

DeltaSigma_C=[160 56 36];
DeltaSigma_R=DeltaSigma_C/gamma_Mf*(N_C/N_R)^(1/3)

%  STRESS AND FORCE
format short G
M=DeltaSigma_R*1e6.*Z % The 1e6 to convert to Pa.
F=M/L
```

Question 2 [1 Mark]

The 6 mm weld is more than suitable for this application because it offers sufficient throat area to result in the toe being the weakest point. 1 Mark

Question 3 [1 Mark]

In this case weld toe dressing (burring, plasma dressing, peening) will have substantial increase in fatigue life. 1 Mark

Question 4 [2 Mark]

Weld toe burring increase the fatigue life at the weld toe only. In this case the weld root is the weakest point and toe burring will have no effect.

2 Marks for knowing only weld toe value changes and other remains same. Give only 1 if they also changed the root and base metal values

Point of crack initiation	**Allowable force range [kN]**
In the base metal	9.6
At the weld toe	4.4
At the weld root	2.1

```
% EFFECT OF BURRING
sprintf('Detail below for weld toe burred')
DeltaSigma_C=[160 56*K_burr 36];
DeltaSigma_R=DeltaSigma_C/gamma_Mf*(N_C/N_R)^(1/3)
format short G
M=DeltaSigma_R*1e6.*Z % The 1e6 to convert to Pa.
F=M/L
```

Question 5 [1 Mark]

The analysis was done assuming that the welded joint is properly surface protected against corrosion. Corrosion affects the endurance below the constant amplitude limit and eliminates the cut-off limit. The calculations were in this case done for stress ranges above the constant amplitude fatigue limit. Therefore, if the un-corroded part is subject to the 3 million cycles over a short period of time before pit corrosion appears, the fatigue life and strength is expected to be the same as calculated. In extreme cases pitting corrosion will reduce the fatigue strength by up to 70%.

Question 6 [1 Mark]

There could be answers different to those in the memo. Mark accordingly.

The weakest point in the design is at the weld toe.

Therefore, changing the connection detail to be a complete penetration butt weld will not have any benefits.

Except for post-weld grinding, dressing or peening, the only other option to increase the fatigue life of the joint is to use cross section with larger section module, Z. This is because the stress range is $\Delta\sigma = \frac{FL}{Z}$. If the force still needs to be applied at distance L, only a larger section module will reduce the stress. Remember the trade-off with crack initiation at the weld root that might need a larger weld size when required. An H-section with same height than the I-beam will offer higher section module and can be used.

3. WELD GEOMETRY CHANGE [WEIGHT = 10/10] – LEAVE OUT, DO NOT MARK

3.1. Problem statement

Figure 4 shows two corner joint configurations tagged Geometry A and Geometry B. The configuration is subject to a horizontal and vertical load F_x and F_y respectively as shown.

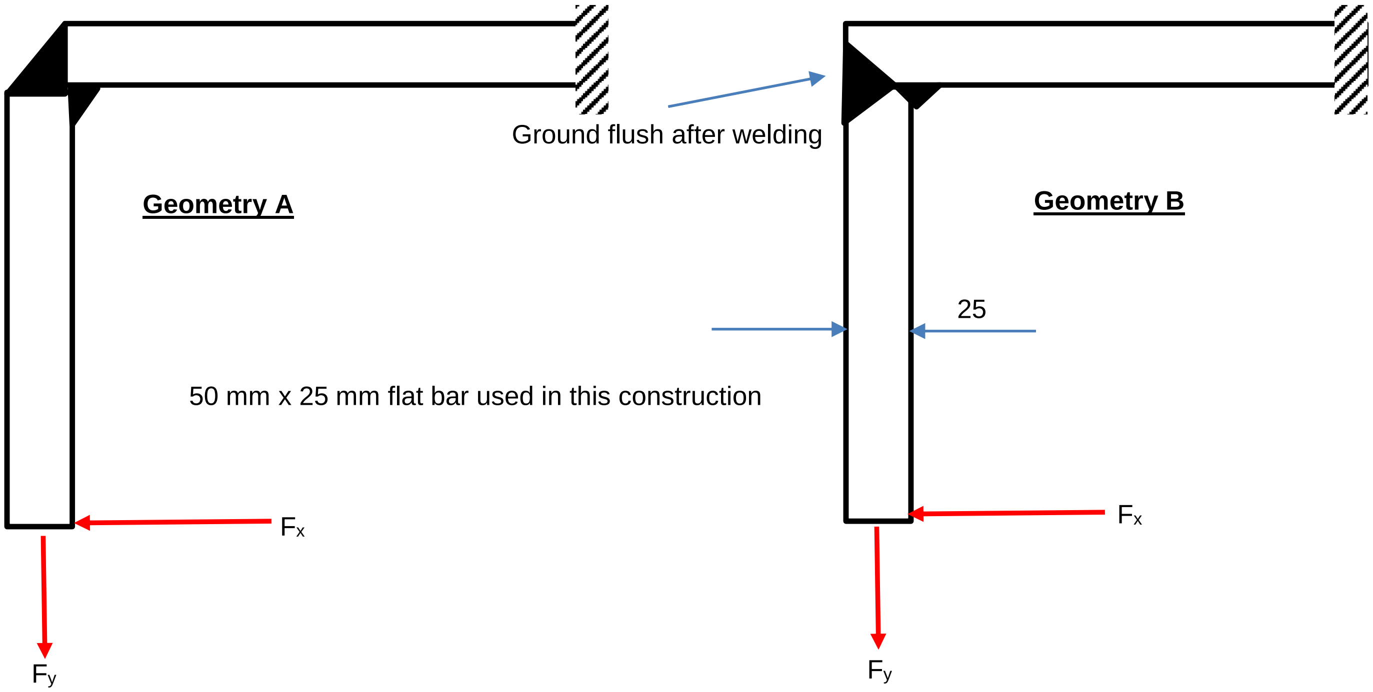


Figure 4: Corner joint configurations Geometry A and B

Please answer the following:

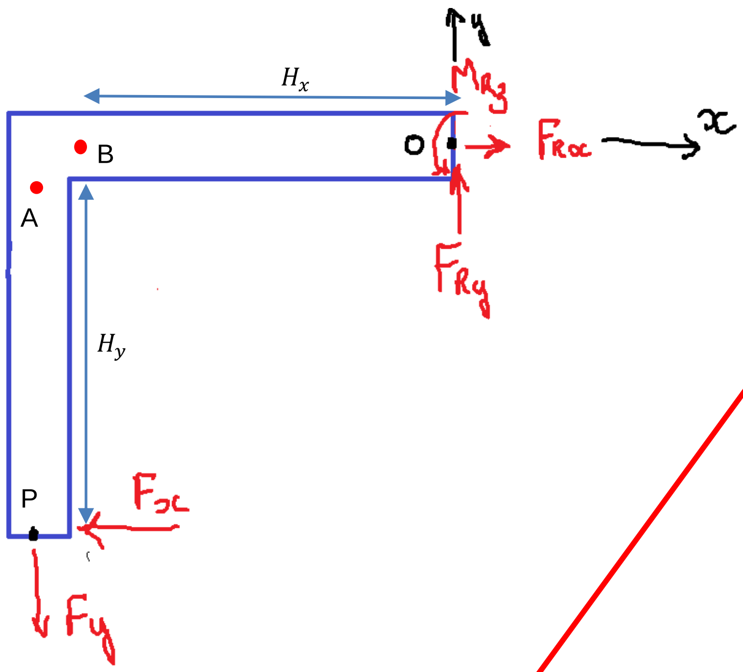
1. On a free body diagram, sketch how you anticipate forces and moments through the joint and plate sections **[25%]**.
2. Compare, with motivations, the fatigue strength of the joint shown by Geometry A and B. **[25%]**.
3. Under which conditions would you recommend the use of the notch stress approach instead of the nominal stress approach to evaluate the fatigue strength of the joints? Motivate clearly. **[25%]**
4. If calculations show that a joint is needed that has ten times the fatigue life the joint in Geometry A, what modifications to the design would you recommend. Clearly motivate your answer by discussing equations and applicable S-N curves. **[25%]**

3.2. Answer

Question 1

The forces and reaction forces are shown in the figure below. The coordinates of the points are as follows:

A$\left(-H_x - \frac{t}{2}, -\frac{t}{2}\right)$; B$(-H_x, 0)$ and P$\left(-H_x - \frac{t}{2}, -H_y - \frac{t}{2}\right)$



The forces and moments at Points A and B are as follows (if small deflections are assumed):

$$\begin{aligned}
F_{An} &= F_y \\
F_{A\tau} &= F_x \\
M_A &= F_x H_y \\
F_{Bn} &= F_x \\
F_{B\tau} &= F_y \\
M_B &= F_x\left(H_y + \frac{t}{2}\right) - F_y\frac{t}{2}
\end{aligned}$$

Where

$F_{A\tau}$	is the shear force at Point A
$F_{B\tau}$	is the shear force at Point B
H_x	is the horizontal distance from the Point B to the reaction forces
H_y	is the vertical distance from Point A to the point of force application
t	is the thickness of the plates

The relative magnitude of the forces as well as the heights H_x and H_y will play a significant role in the deflection of the part as well as how the moments will dominate to determine points of expected crack initiation.

Question 2

Comparing Geometry A with Geometry B referring to the figure below. When the term crack initiation is used to compare fatigue strength, this refers to where the crack is expected to initiate first in the joint.

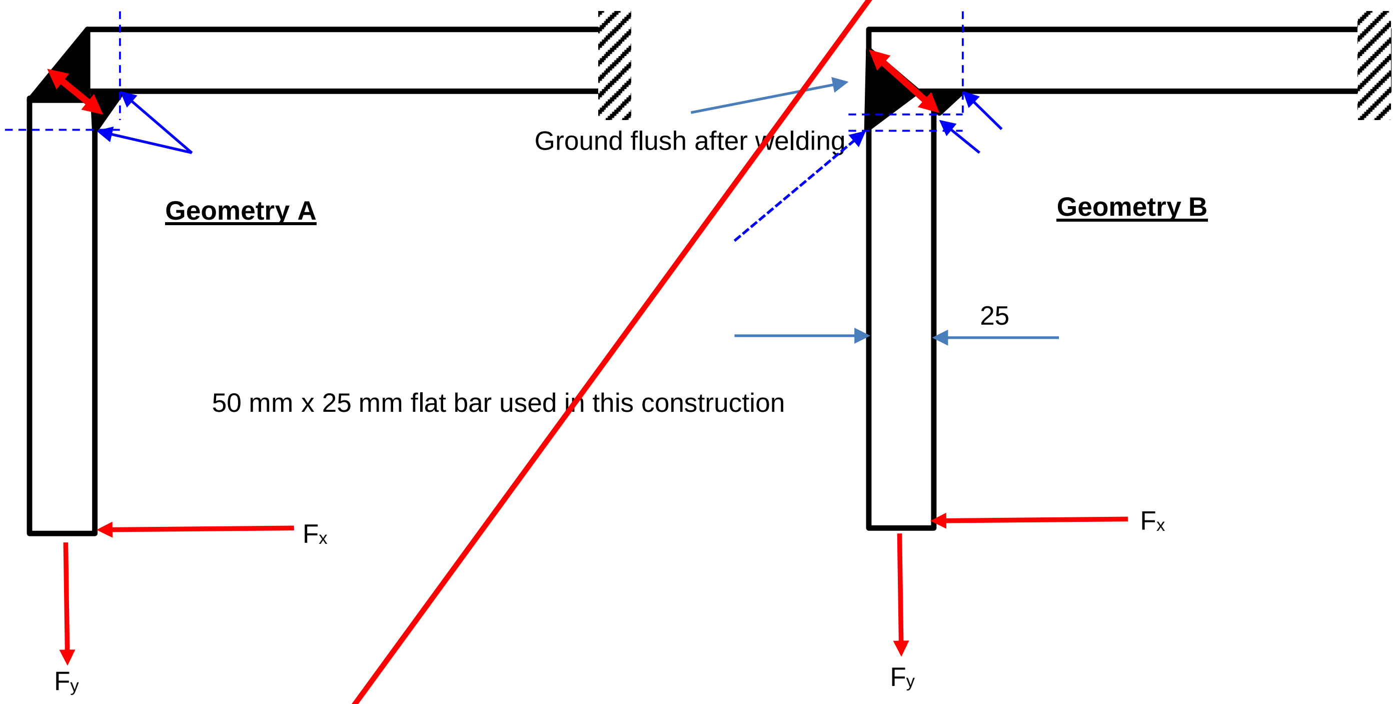
Depth

The red arrow indicate the depth of the geometries at the weld. As shown, Geometry B offers a deeper section than Geometry A because of the corner.

Point of crack initiation

For Geometry A the most likely point of crack initiation is at the weld toes of the smaller weld on the inside. The same applies for Geometry B. These points are indicated by the blue arrows. The specific point of crack initiation depends on the relative force magnitudes as well as the dimension of the part. For Geometry B, crack initiation could also occur at the weld toe of the flush ground weld. However, the ground weld will have a detail category higher than the weld on the inside. Therefore, crack initiation at the toe of the weld on the inside is expected. For Geometry A it is unlikely that a crack will initiate at the weld on the outside because the cross-section is deeper at the outside weld toe than at the weld toe of the inside weld.

Based on these, from fatigue point of view, the Geometries offer the same fatigue strength for crack initiation at the weld toe on the inside. The moments and forces are the same for bending and normal stress. The detail category is similar, and, the point at the weld toe of the inside weld is point with lowest detail category in the joint.



50 mm x 25 mm flat bar used in this construction

Question 3

Nominal stress and the tables is very useful for manual calculations. The geometric stress (hot-spot stress) method offers a useful technique with finite element analysis using shell or solid elements. If the weld detail is not covered by the tables (for normal and geometric stress analysis), it is difficult to manually calculate the stress concentration in the joint caused by the joint geometry (not including the stress concentrations by the weld toe and root detail), a notch stress approach must be followed. Or, the welded joint fatigue strength need to be verified by testing.

In Geometry A and B above, manual stress calculation with tabled detail category is sufficient for fatigue analysis. However, if the weld geometry is changed to such extent that accurate geometry dependent stress concentration factors could not be calculated and the welds are not covered by the tables, a notch fatigue analysis will provide reliable fatigue life.

Question 4:

Assume that the stress ranges are such that the stresses lie on the first section of the S-N curve. **[Mark according to the student's assumptions]**

If a life ration of 10 is required, it would require the following ratio on stress range:

$$\begin{aligned} \Delta\sigma_1 N_1 &= \Delta\sigma_2 N_2 \\ \left(\frac{\Delta\sigma_2}{\Delta\sigma_1}\right)^m &= \frac{N_1}{N_2} \\ \frac{\Delta\sigma_2}{\Delta\sigma_1} &= \left(\frac{N_1}{N_2}\right)^{\frac{1}{m}} \\ &= 0.1^{\frac{1}{3}} \\ &= 0.46 \end{aligned}$$

There are the following approaches to achieve this:

1. The detail category of the weld detail must be increased by 2.15:
    a. This will imply that there cannot be weld detail. For example, if the detail category was 63, a detail category of 63 × 2.15 = 135 is required. There is no weld detail that can offer this. However, the parent metal with no welding has a detail category 160, which is sufficient. Therefore, the one option is to remove the welds and bend the profile to provide the geometry required.
2. The stress must be reduced by factor 2.15:
    a. This can be achieved by increasing thickness of the cross section.

4. ADVANCED WELD FATIGUE DECISION-MAKING [WEIGHT = 30/10]

4.1. Problem Statement

A longitudinal weld is used with cope holes as shown in Figure 5. The thickness of the structural steel web and the flange is 20 mm. The cope hole height is 20% of the web height. There is no shear stress in the web at the weld ends. The flange normal stress spectrum over a period of two years is summarised in Table 2. Assume a damage tolerant structure with high consequence of failure.

Table 2: Stress spectrum on the joint over a period of two years

σ_{max} [MPa]	σ_{min} [MPa]	Number of cycles
43	0	1,000,000
30	-20	800,000
20	-60	400,000

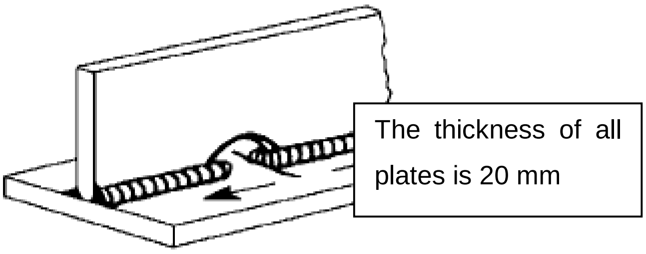


Figure 5: Intermittent fillet weld on part.

Please answer the following (Please use BS EN 1993-1-9 as reference):

1. If the stress spectrum above refers to a block loading applied to the joint over a period of 2 years, what estimate of fatigue life would you make for the welded joint for a probability of failure of 5%? **[64%] 7**
2. Where do you expect the weld detail to fail, please motivate. **[4%] 1**
3. Do you need to consider thickness effects on the fatigue life? Please motivate. **[4%] 1**
4. What first order estimate for fatigue life would you recommend when peening is done to the surface before the joint is put in service? That is, just give a rough factor. **[8%] 1**
5. What estimate for fatigue life would you make if toe burring has been applied? **[8%] 5**
6. To which joint type do you recommend the joint should be modified to increase fatigue life? **[4%] 1**
7. If the joint could not be expressly classified, as what detail category would you treat it in this case? **[8%] 1**

4.2. Answer

Question 1 [7 Marks]

Partial factor for fatigue [1 Mark]

According to the detail supplied, the assessment method is damage tolerant with a high consequence of failure that gives a partial factor for fatigue strength of 1.15 as shown below.

Table 3: Partial factor for fatigue strength γ_{Mf}

Assessment method	Consequence of failure	
	Low Consequence	High Consequence
Damage tolerant	1.00	1.15
Safe Life	1.15	1.35

Weld detail category [1 Mark]

According to EN 1993-1-9 Table 8.2 Detail 9 the detail category for the weld with cope hole (cope hole height not greater than 60 mm) for crack initiation at the toe of the weld through the cope hole is 71. According to BS 7608:2014 Table 3 Type No. 3.5 for crack initiation at same position the Class for nominal stress analysis is Class F, which provides an equivalent characteristic strength at 2 million cycles of stress range 70 MPa according to BS 7608:2014 Figure 10. Therefore, for the calculations in this case, the detail category for the cope hole will be taken as 71.

Modifying factors

No additional modifying factors were prescribed.

Thickness below limit. No post-weld treatments. Room temperature. Assumed used in non-corrosive environment.

S_r-N curve

The S_r-N curve for the material is modelled by the following according to EN 1993-1-9 (if there is at least one stress range exceeding the constant amplitude fatigue limit, $\Delta\sigma_D$, if not, infinite life result):

$$N_R = \begin{cases} \left(\frac{\Delta\sigma_C}{\Delta\sigma_R}\right)^3 N_C & 1.5 f_y \geq \Delta\sigma_R \geq \Delta\sigma_D \\ \left(\frac{\Delta\sigma_D}{\Delta\sigma_R}\right)^5 N_D & \Delta\sigma_D > \Delta\sigma_R \geq \Delta\sigma_L \\ \infty & \Delta\sigma_r < \Delta\sigma_L \end{cases}$$

$$where$$

$$\Delta\sigma_D = \Delta\sigma_C \left(\frac{N_C}{N_D}\right)^{m_1}$$

$$\Delta\sigma_L = \Delta\sigma_D \left(\frac{N_D}{N_L}\right)^{m_2}$$

Damage calculation

The Miner rule was applied to calculate damage and estimate the fatigue life as summarised in the table below. As shown, the stress spectrum has stress ranges exceeding the constant amplitude fatigue limit and damage calculation is required. If this was not the case, infinite life would have resulted.

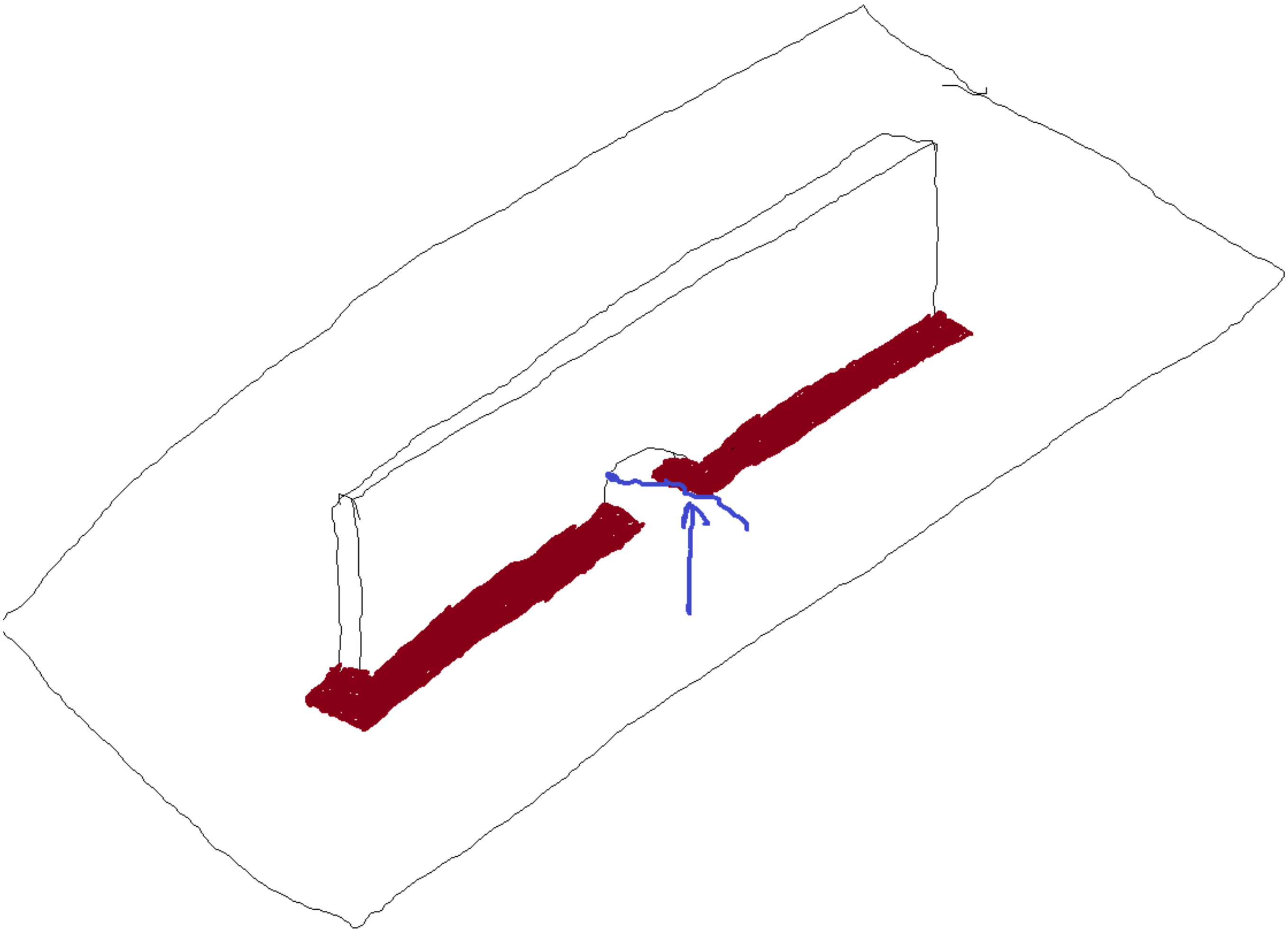
For the information given, the fatigue life for 5% probability of crack initiation is 2.5 years. [5 Marks for correct answer, 2 for correct procedures but wrong answer.]

Detail category	71	
Partial factor for fatigue strength	1.15	
Reduced reference fatigue strength	61.7	MPa
Endurance: Reduced fatigue strength	2.00E+06	Cycles
Endurance: Constant amplitude fatigue limit	5.00E+06	Cycles
Slope 1	3	
Slope 2	5	
Const. Ampl. fatigue strength	45.49	MPa
Cut-off limit endurance	1.00E+08	Cycles
Cut-off limit stress range	24.99	MPa
Maximum stress range in stress spectrum	80.00	MPa
Was the constant amplitude fatigue limit exeeded?	**Yes**	

Stress-max	Stress-min	Range	Cycles	Endurance	Damage	
43	0	43	1 000 000	6 625 168	0.151	
30	-20	50	800 000	3 765 317	0.212	
20	-60	80	400 000	919 267	0.435	
			Total damage per block		**0.799**	
			Duration of block		**2.000**	**years**
			Life in blocks		**1.252**	
			Life in block durations		**2.505**	**years**

Question 2 [1 Mark]

The crack is expected to initiate at the toe of the weld protruding through the cope hole as shown below. If the weld did not go through the hole, at the end of the longitudinal weld.



Question 3 [1 Mark]

No. The crack will initiate at the notch produced by the weld toe that is not sensitive for thickness.

Question 4 [1 Mark]

Peening will increase fatigue life in this case. According to IIW the maximum increase in detail category dependent characteristic strength is 1.6, limited by FAT 125. However, the detail category applicable in this case is 71. Peening will therefore increase the characteristic strength to 114 MPa. Therefore, for argument in this case it can be assumed that a strength increase of 1.6 can be achieved. Note, some students may use 1.3. Evaluate the argument and mark accordingly.

For a strength increase, the following increases in life is possible:

$$\frac{N_2}{N_1} = \begin{cases} 1.6^3 = 4 & 1.5\mathrm{f_y} \geq \Delta\sigma_2 \geq \Delta\sigma_D \\ 1.6^5 = 10 & \Delta\sigma_\mathrm{D} \geq \Delta\sigma_2 \geq \Delta\sigma_L \end{cases}$$

Depending on the stress spectrum it could be between 4 to 10 times longer life for materials with yield strength more than 355 MPa.

If the student used 1.3, the values would be:

$$\frac{N_2}{N_1} = \begin{cases} 1.3^3 = 2 & 1.5\mathrm{f_y} \geq \Delta\sigma_2 \geq \Delta\sigma_D \\ 1.3^5 = 4 & \Delta\sigma_\mathrm{D} \geq \Delta\sigma_2 \geq \Delta\sigma_L \end{cases}$$

In this case the increase in fatigue life will be between 2 and 4 depending on the distribution in the stress spectrum.

Note, that there could be cases where this increase could result in infinite life, for example where the maximum stress range is just above the constant amplitude fatigue limit and the peening increases the constant amplitude fatigue limit above the maximum stress range.

Memo notes:

1. Mark according to the argument of the student.
2. The calculations given above are not necessary.
3. The student is allowed to reference to the 2 to 3 times in the additional notes handed out.
4. The student must identify that in this case peening will increase life.

Question 5 [5 Marks]

According to IIW Bulletin 520 toe burring will increase the characteristic strength by factor 1.3 to maximum 112. In this case the characteristic strength will increase to 1.3 × 71 = 92.3 MPa. This is below 112 MPa. The calculation was then repeated as before as shown below.

From this it is clear that there are still stress ranges exceeding the modified constant amplitude fatigue limit, which implies finite life. The life was calculated as 6.5 years. This is 6.5/2.5 = 2.6 times increase in fatigue life.

[5 Marks for correct answer. 2 for correct procedure but wrong answer]

Detail category				71		
Partial factor for fatigue strength				1.15		
Toe burring				1.3		
Reduced reference fatigue strength				80.3	MPa	
Endurance: Reduced fatigue strength				2.00E+06	Cycles	
Endurance: Constant amplitude fatigue limit				5.00E+06	Cycles	
Slope 1				3		
Slope 2				5		
Const. Ampl. fatigue strength				59.14	MPa	
Cut-off limit endurance				1.00E+08	Cycles	
Cut-off limit stress range				32.48	MPa	
Maximum stress range in stress spectrum				80.00	MPa	
Was the constant amplitude fatigue limit exeeded?				**Yes**		
Stress-max	Stress-min	Range	Cycles	Endurance	Damage	
43	0	43	1 000 000	24 598 786	0.041	
30	-20	50	800 000	11 571 934	0.069	
20	-60	80	400 000	2 019 629	0.198	
				Total damage per block	**0.308**	
				Duration of block	**2.000**	**years**
				Life in blocks	**3.248**	
				Life in block durations	**6.497**	**years**

Question 6 [1 Mark]

Modify to continuous longitudinal weld in which case the detail category will increase from 71 to 100. Or, to an intermittent longitudinal weld which has a detail category 80.

Question 7 [1 Marks]

BS 7608 Answer:

The weld is non-load carrying welds in this case. For unclassified details similar to that shown in the problem, use Class G weld detail parameters or find applicable fatigue curves in published literature. Special tests can also be carried out on the unclassified joint detail to obtain applicable fatigue curves. **[1 Marks]**

IIW Bulletin 520 Answer **[1 Mark]**

For unclassified weld detail, apply the effective notch stress method.

BS EN 1993-1-9 Answer **[1 Mark]**

According to BS EN 1993-1-9 (2005:16):

1. When test data were used to determine the appropriate detail category for a particular constructional detail, the value of the stress range $\Delta\sigma_C$ corresponding to a value of $N_C = 2 \times 10^6$ cycles were calculated for a 75% confidence level of 95% probability of survival for $logN$, taking into account the standard deviation and the sample size and residual stress effects. The number of data points (≥10) was considered in the statistical analysis (see Annex D of EN 1990).

2. The National Annex may permit the verification of a fatigue strength category for a particular application provided that it is evaluated in accordance with the Note above.
3. Test data for some details do not exactly fit the fatigue strength curves in the figure below. In order to ensure that non-conservative conditions are avoided, such details, marked with an *, are located one detail category lower than their fatigue strength at 2×10^6 cycles would require. An alternative assessment may increase the classification of such details be one detail category provided that the constant amplitude fatigue limit $\Delta\sigma_D$ is defined as the fatigue strength at 10^7 cycles for $m = 3$.
4. Use the weakest detail category of 36 in the tables.